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Relative Source Contributions of Diet and Air to Ingested Asbestos Exposure

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Reliable assessments of the relative contributions of diet (food, beverages, and orally administered drugs) and air (inhaled fibers) to total ingested asbestos exposure are not feasible due to the paucity of quantitative data on the subject. Instead, scenarios for both modes of exposure were developed from the limited information available to give crude estimates of ingestion of asbestos from these routes. They suggest that such sources are potentially significant relative to the contribution of asbestos exposure derived from drinking water. Research recommendations are discussed.

The general public has become aware of the potential gastrointestinal exposure to asbestos fibers from drinking water flowing through asbestos cement pipe or from fibers derived from natural sources of asbestos in rivers or reservoirs. However, most people are unaware that diet and air may also contribute significantly to the ingested asbestos exposure. The following is a discussion of the potential relative source contributions of diet, air and drinking water sources to ingested asbestos exposure. Information gaps in this area exist that preclude an accurate measure of the total ingested load of asbestos. The types of studies needed to fill these gaps are identified.

Asbestos in Dietary Materials

Only sparse data are available upon which one can estimate with any assurance the magnitude of asbestos exposure to the gastrointestinal tract from airborne and dietary sources, however, limited information is available for some sources that allow a crude measure of the ingested asbestos load to be calculated. Dietary materials that have been reported to contain, or are likely to contain, asbestos include foods such as vegetable oil, lard, mayonnaise, ketchup, meats (*1–3*) and beverages such as beers, sherries, ports, vermouth and soft drinks (*4–6*). In processed or filtered foods, the contamination is most likely due to the filtration process during which asbestos fibers are released into the processed materials. Other direct or indirect sources of asbestiform minerals in the food industry are in building materials, e.g., cement floor and ceiling tiles, pipe coverings and brake linings of transport vehicles (*7*). In addition, tremolite asbestos is found in talc-coated rice and chewing gum, as well as in oral drugs containing talc as an incipient in compressed tablets, as a dusting powder in capsules, and, less frequently, as a filler in the capsules (*8*).

Contamination by asbestos is so common that many, if not most, foods may contain some asbestos contamination (P. McGrath, FDA, personal communication). Unfortunately, there is presently no established program to examine exhaustively dietary materials for their asbestos content.

Limited, but important, quantitative data on the concentrations of asbestos in ingested sources are given in Table 1. In alcoholic and nonalcoholic beverages, Cunningham and Pontefract (*5*) reported asbestos concentrations ranging from 1.1 to 12.2×10^6 fibers/L as measured by the transmission electron microscope (TEM). The asbestos content of a sample of talc-coated rice destined for Japanese consumers was estimated by Merliss (*1*) to contain 3.7×10^6 fibers/g as measured through the light optical microscope (LOM). The asbestos concentration in drugs, including three brands of aspirin, has been determined by Nicholson (*9*) to range from 120 to 150 ng/g.

Using this information, a scenario could be constructed along the following lines: John Q. Public is an "average" individual who daily

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Table 1. Concentration of asbestos in dietary substances.[a]

Dietary substance	No. of observations	Concentration, fibers/L
Beverages		
Beer	4 types	1.1–6.6 × 10^6 (EM)
Sherry	3 types	2–2.6 × 10^6 (EM)
Port	1 type	2.1 × 10^6 (EM)
Vermouth	2 types	1.8–11.7 × 10^6 (EM)
Soft drinks	4 types	1.7–12.2 × 10^6 (EM)
Talc-coated rice	Not reported	3.7 × 10^6 fibers/g (LOM)
Drugs (aspirin)	3 brands	120–150 ng/g

[a]Extracted from Office of Toxic Substances data (*10*).

Table 2. Dietary calculations.[a]

Material (portion)	Calculation	Fibers
1 beer (12 oz)	(12 oz) (0.03 L/oz) × [6.6 × 10^6 fibers/L (EM)]	2.4 × 10^6 (EM)
Rice (3 oz)	(3 oz) (28 g/oz) [3.7 × 10^6 fibers/g (LOM)]	310.8 × 10^6 (LOM)
	310.8 × 10^6 fibers (LOM) × 1000 EM fibers/LOM f[a]	310.8 × 10^9 (EM)
	310.8 × 10^6 fibers (LOM) × 25 EM fibers/LOM fiber[b]	7.8 × 10^9 (EM)
Aspirin (0.9 g)	(0.9 g) (150 ng/g) [30 fibers (LOM)/ng][c] × 1,000 EM f/LOM f[a]	4.05 × 10^6 (EM)
		Total daily dose of fibers = 311 × 10^9 or 7.8 × 10^9 (EM)
Yearly ingested dose		
With talc		1.14 × 10^{14} or 2.85 × 10^{12}
Without talc		2.35 × 10^9

[a]Data of Winer and Cossett (*11*).
[b]Data of Lynch et al. (*12*).
[c]U.S. EPA data (*13*).

drinks one beer (0.36 L), eats a moderate helping of Japanese-style rice (84 g), and takes three aspirin (0.9 g) to thin his blood (or so he has heard). Using the highest concentration of asbestos reported for beer and aspirin and maximum or minimum conversion factors for the number of EM fibers/LOM fiber (Table 2), we discover that John Q's potential yearly dietary consumption is roughly equivalent to 1.4 × 10^{14} fibers (maximum conversion factor) or 2.85 × 10^{12} fibers (minimum conversion factor) in a diet including talc-coated rice. Without talc-coated rice, the yearly ingested dose is 2.35 × 10^9 fibers (Table 2).

Airborne Asbestos

Estimation of the contribution of airborne asbestos to "secondarily" ingested (swallowed) asbestos exposure is complex. Airborne asbestos enters the body mainly through the nose but also through the mouth. Some fibers may move from these portals of entry to the back of the throat and be swallowed. Much of the inhaled asbestos moves into the tracheobronchial tree to the lungs. Material is cleared from these areas back up the trachea and is then swallowed.

Ingestion of airborne contaminants is dependent upon their patterns of deposition within the nasopharyngeal area and respiratory tract and the rates and pathways for their clearance from the deposition sites to the gastrointestinal tract (*14*).

Generally speaking, inert, insoluble particles deposited in the tracheobronchial area can be cleared by the mucociliary escalator within 1 day via the larynx (*15*). Material deposited in the respiratory epithelium of the alveoli is cleared through nonabsorptive and absorptive processes. Phagocytosis of fibers (approximately 12 μm length or less) by macrophages provides a widely accepted nonabsorptive clearance mechanism for fibers. The phagocytic process is complete within 2 weeks of exposure (*14, 16*). Presumably, macrophages transport asbestos fibers proximally up the respiratory tract for subsequent swallowing (*14*) and passage to the gut. Long asbestos fibers, primarily those > 10 μm length, will remain permanently in the alveoli or penetrate the alveolar wall (*16*).

Estimation of the load of asbestos to the gastrointestinal tract from inhaled fibers must take into account the sites of deposition and their related rates of clearance. The nasal sufaces, nasopharyngeal, oropharyngeal, tracheobronchial and alveolar regions constitute the major sites of concern. Deposition refers to total fiber concentration deposited in any region of the body following inhalation. For the purposes of this discussion, clearance refers to the processes that result in eventual swallowing of the fibers; e.g., clearance from the nasal mucosa and tracheobronchial regions via mucociliary clearance.

Although no attempt has been made to define accurately the quantitative relationships between inhalation of respirable asbestos fibers (of various size categories) and their subsequent ingestion, there is information that allows for a tentative estimate of ingested or inhaled asbestos, which will be compared to previous quantitative measures developed by other investigators (*17, 18*).

The current analysis relies upon studies performed on non-asbestiform material, namely spherical or amorphous inorganic and organic particles. These studies are reviewed by Lippmann et al. (*14*). In addition, some data are available on asbestos and man-made fibers (*19, 20*).

Exposure scenarios will be considered for two fiber size distributions, i.e., "small" environmental and "large" occupational fibers. Nicholson (*21*) has reported that asbestos fibers in ambient air tend to be very small, with some fibers up to about a micron or so in length, but most are individual fibrils with lengths as short as 0.1 μm and diameters of 0.02–0.05 μm. Although more recently Nicholson has indicated that asbestos fiber sizes from environmental exposure are more equivalent to those from occupational exposures based on monitoring practices in Germany, for the purposes of this discussion we will assume that environmental fiber samples are "small."

The small asbestos particles will be considered as equivalent to more conventional aerosol materials at aerodynamic or linear diameters of 1 μm or less. This particle size range will be deposited primarily in the alveolar region (*14*), with a total deposition of approximately 20% of the inhaled aerosol. The rate of clearance can be estimated from the work of Morgan and Holmes (*20*), who reported that short glass fibers (5 μm length × 1.5 μm diameter) were 80% cleared from rat lungs by 1 yr after deposition.

For the purposes of this paper, it will be assumed that 20% of inhaled asbestos in the ambient air will be deposited and 80% of the deposited asbestos will be cleared. The "average" person is assumed to work for 8 hr/day in this setting and then rests for 16 hr (see Table 3).

In an occupational setting, "large" asbestos fiber lengths are likely to be encountered that have wider diameters than are seen with the "small" environmental exposure fibers. Morgan and Holmes (*20*) have studied the deposition and clearance of glass fibers in rats (1.5 μm diameter × 10 and 60 μm length). They found evidence suggesting 100% deposition of these fibers in the lungs. For UICC chrysotile A and B, crocidolite, amosite, and anthophyllite, which generally have much finer average fiber diameters than glass fibers, the authors reported a 50% deposition rate. The 10 μm glass fibers were cleared to the extent of 70% at 1 yr.

Table 3. *Estimated ingested dose following ambient airborne exposure.*

	Airborne concentration	Yearly ingested dose (EM fibers)
Office of Toxic Substances estimate[a]		
Ambient air near Union Carbide Mill and Waste Pile (King City, CA)	99.8×10^6 fibers/m^3	1.17×10^{11} fibers[c]
	1.03×10^6 fibers/m^3	1.20×10^9 fibers[c]
Ambient air near Johns-Manville mill and waste dump (Coalinga, CA, 1973)	593×10^6 fibers/m^3	6.93×10^{11} fibers[c]
Office of Water Regulations and Standards estimates[b]		
Range of 24-hr chrysotile asbestos in ambient air of U.S. cities	100 ng/m^3 (high value)	1.1×10^{10} fibers[d]
	1 ng/m^3 (low value)	1.1×10^8 fibers[d]
Ambient air in school	2,000 ng/m^3	2.19×10^{11} fibers[d]
Home of asbestos workers (maximum value)	5,000 ng/m^3	5.48×10^{11} fibers[d]

[a]Source of exposure and selected concentrations derived from OTS data (*10*).
[b]U.S. EPA data (*18*).
[c]*Yearly dose calculation: (concentration in air) × (20 m^3 air inhaled/L-day) × (365 days/yr) × (20% deposition) × (80% clearance to* gastrointestinal tract). It is assumed that the average person performs 8 hr moderate exercise/day and 16 hr/day at rest in the ambient environment. Daily inhalation volume = [(1450 cc/breath × 8 hr) + (800 cc/breath × 16 hr)] × 15 breath/min × 60 min/hr × m^3/10^6 cc] = 20m^3/d.
[d]Yearly dose calculation: (concentration in air) × (EM fibers/ng: See Table 2) × 10 m^3 air inhaled/day) × (365 days/yr) × (100% deposition and clearance).

In this paper it will be assumed that occupational exposure to "large" asbestos fibers will occur with a 50% deposition efficiency in the respiratory tract and 70% clearance. Occupational exposures are calculated for the work environment only; general ambient exposures outside of the workplace are not included (see Table 4).

Asbestos in Drinking Water

The mean asbestos concentrations (TEM) from a large number of drinking water sources in the United States have been reported by Millette et al. (*23*) to range from below detectable limits (BDL) to over 1 billion fibers/L. Most asbestos concentrations were BDL or not statistically significant (NSS). Only 11% were greater than 10×10^6 f/L. (Note: BDL refers to any result lower than the detectable limit that would be determined if one fiber were counted, using electron microscopy, and the appropriate calculations were made; NSS refers to fiber counts under 5 fibers that give upper and lower confidence limits of $\pm 100\%$.) Several different analyses of waterborne asbestos have been made and are developed in Table 5.

Relative Sources of Ingested Asbestos

It is widely recognized that asbestos in drinking water may contribute a significant load of the material to the gastrointestinal tract. Using the estimates from the present analysis as well as those developed by other authors, one can see that the annual doses of ingested asbestos for drinking water in the United States could potentially range from 9×10^5 to 4×10^{11} fibers. The surprising finding from preliminary data for dietary and airborne sources indicates that these sources also may pose a significant dose of asbestos to the gastrointestinal tract. It would seem that airborne exposures may deliver from 1.2×10^9 to 9×10^{12} asbestos fibers to the gut, while dietary sources may give 2.4×10^9 to 1.4×10^{14} asbestos fibers yearly. In fact, a comparison of the relative contributions from the various routes of exposure indicates that diet is highest, air is second, and water is the lowest.

It is recognized that these estimates are exceedingly tentative, but they help to point out that sources other than drinking water may deliver

Table 4. Estimated ingested dose following occupational airborne exposures.

	Airborne concentration	Yearly ingested dose (EM fibers)[a]
Office of Toxic Substances estimate[b]		
Fiber release from tearing, crumpling, and cutting asbestos paper	262×10^6 f/m^3	2.30×10^{11} f
Office of Water Regulations and Standards estimates[c]		
Occupational	100,000 ng/m^3	8.76×10^{12} f
American Water Works estimates[d]		
Chrysotile miners and millers (maximum value)	20 mppcf[e]	7.56×10^{11} f
Asbestos production and maintenance workers (minimum value)	2.5 mppcf[e]	1.89×10^{11} f
Chrysotile miners and millers (minimum value)	0.25 mppcf[e]	9.45×10^{9} f

[a]Yearly dose estimates, OTS: (concentration in air) × (10 m^3 air inhaled/day) × (250 days/yr) × (50% deposition) × (70% clearance to gastrointestinal tract). It is assumed that the average person performs 8 hr moderate exercise/day during work. No exposure is assumed during leisure hours. Daily inhalation volume = (1450 cc/breath × 8 hr) × 15 breath/min × 60 min/hr × m^3/10^6 cc = 10 m^3/day.

Yearly dose estimate, OWRS: (concentration in air) × (EM fiber/ng: See Table 2) × (8 m^3 air inhaled/day) × (365 day/yr) × (100% deposition and clearance).

Yearly dose estimate, AWWA, for miners and millers: [Concentration (mppcf)] × [2 fiber/cc (LOM)/1 mppcf] × [25 EM fiber/1LOM fiber] × [volume inhaled = 10^3 cc/L × 16 L/min × 420 min/day × 5 days/wk × 50 wk/yr] × [deposition/clearance: 45% (f = 0.5 × 5 μm/EM fiber)].

McDonald (*22*) estimates mppcf = 2 f/cc (LOM); Lynch (*12*) 25 EM fibers/LOM fiber; 1 LOM fiber = 1 × 20 μm, 1 EM fiber = 0.5 × 5 μm; 25 EM fiber per LOM fiber; 1 LOM fiber = approximately 0.000040178 μg; 1 EM fiber = 0.000002645 μg.

Yearly dose estimates, AWWA, for asbestos production and maintenance workers: Same calculations as for miners and millers except 4 fibers/cc (LOM)/L mppcf is used based on Lynch's studies (*12*).

[b]OTS data (*10*).

[c]U.S. EPA data (*18*).

[d]American Water Works Assoc. data (*17*).

[e]mppcf = million particles per ft^3/per year.

Table 5. Estimated ingested dose from drinking water.

	Concentration in water	Yearly ingested dose (EM fibers)[d]
Office of Toxic Substances estimate[a]		
Asbestos-contaminated water (Bishopville, SC)	547×10^6 fibers/L	3.99×10^{11}
Natural contamination: geological source (San Francisco, CA)	130×10^6 fibers/L	9.49×10^{10}
Groundwater (ambient)	3.2×10^5 fibers/L	2.34×10^8
Office of Water Regulations and Standards estimates[b]		
Survey of drinking water	100×10^6 fibers/L (high value)	7.3×10^{10}
	1×10^5 fibers/L (low measured value)	7.3×10^7
American Water Works estimates (municipal water systems)[c]		
Memphis District System	1.70 μg/L	4.69×10^8
Providence District System	0.27 μg/L	7.45×10^7
Saginaw Source	0.0032 μg/L	8.83×10^5

[a,b,c]See Table 4 for sources of exposure and selected concentrations.
[d]Yearly dose estimates, OTS, OWRS: (concentration in water) × 2 L/day) × (365 days/yr).
Yearly dose estimates, AWWA: (concentration in water: μg/gal × gal/L) × (2 L/day) × (EM fibers/μg: see Table 4) × (365 days/yr).

significant amounts of asbestos to the gastrointestinal tract. To the extent that these exposures to the gut may pose health hazards, there may be great reason for trying to define more accurately the contributions of each.

Information Gaps: Dietary Sources

Methods to isolate asbestos from a variety of foods and beverages have been developed (*3, 24*) utilizing SEM and energy dispersive spectroscopy (EDS) analysis. Although these methods appear to provide practical, workable protocols for the potential diagnostic and/or regulatory application, it must be recognized that each food category may present a new set of analytical difficulties that must be resolved. Nevertheless, such methods could be used to examine rigorously the various categories of foods, beverages, or orally administered drugs within the appropriate industries. It is only then that an accurate, quantitative assessment of dietary sources of asbestos can be determined. Estimates of the exposed subpopulation of humans to these materials should also be determined.

Information Gaps: Airborne Sources

The contribution of asbestos to the ingestion exposure from inhalation of airborne fibers has not been critically examined. Experimental and theoretical evaluation of this area would allow accurate dose determinations. Such information could also be applied to any fiber type, both mineral and synthetic, in environmental settings ranging from the occupational to ambient levels. Evaluation requires exposure of animals to a number of fiber size ranges and types with short- and long-term follow-up of the subsequent deposition, retention, and clearance of these fibers. Consideration of the anatomic difference in various species of animals versus humans must also be considered.

Finally, it might be useful to have geographic site-specific data on both ambient water and air concentrations in order to make an accurate comparison of the relative contribution of each source to ingested asbestos exposure.

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